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(54) Abstract Title

Low cost apparatus and method for manufacturing of light gauge steel strip

(57) The invention relates to a method for the manufacture of light gauge steel strip comprising, sequentially, continually casting steel 1, cutting or shearing 2 the hot cast steel into slabs and charging into a furnace which either reheats and/or homogenises the temperature and metallurgical quality of the material, descaling the steel 4, and then reducing the steel in a roughing stand and then rolling in a Steckel mill 7, or reducing directly in a Steckel mill wherein the hot steel strip exits the Steckel mill with a gauge of approximately 1 mm and is passed in tandem into a finishing mill. Zoned cooling units 14 are arranged between the Steckel mill exit and the finishing mill 15 to homogenise the temperature along the length and width of the strip and the cooling units may be adjusted to enable a wide range of entry temperatures of the strip to the finishing stand such that the steel strip entering the finishing stand may be in either the intercritical or ferritic phase.

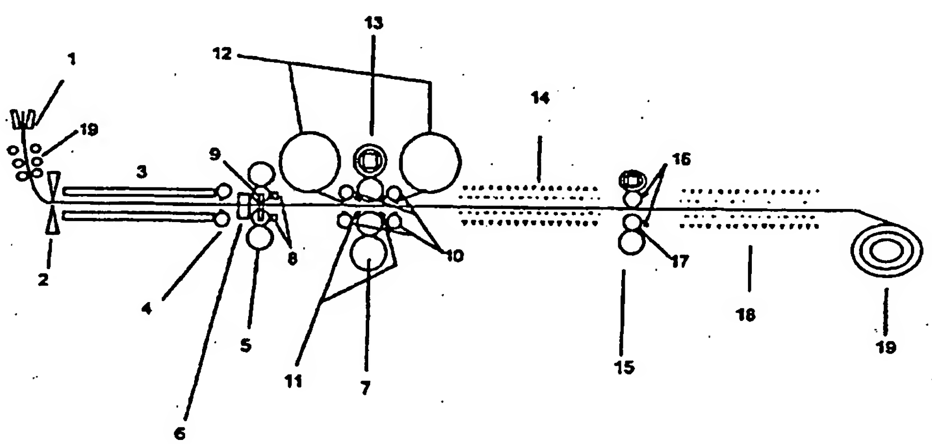

Figure 2

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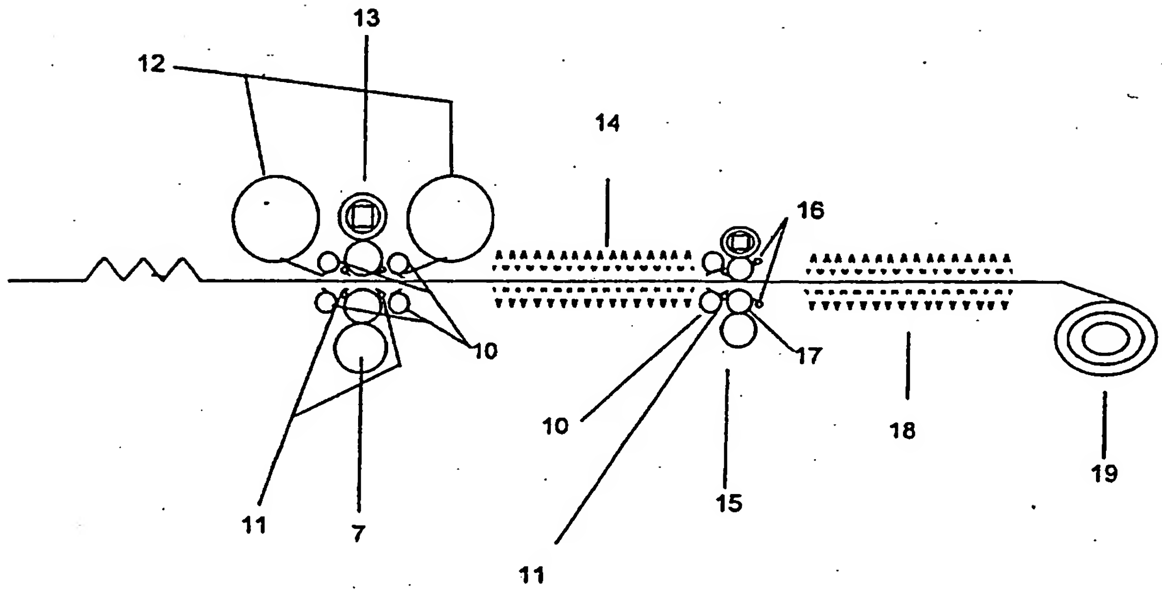

Figure 1

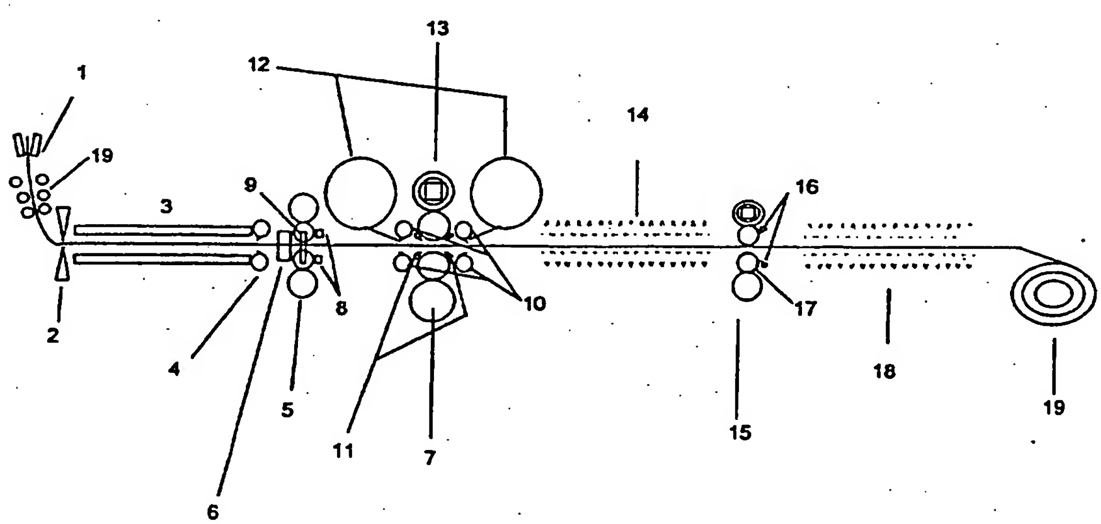

Figure 2

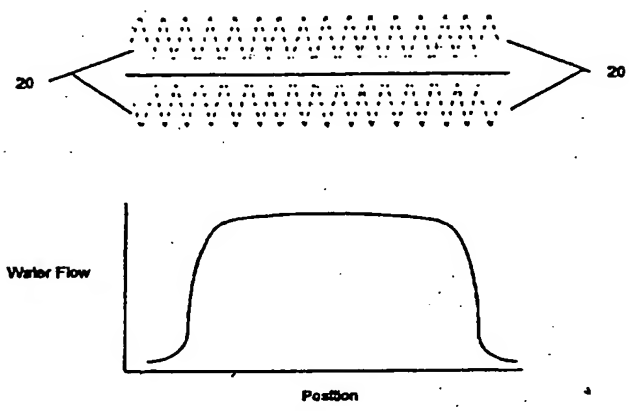

Figure 3

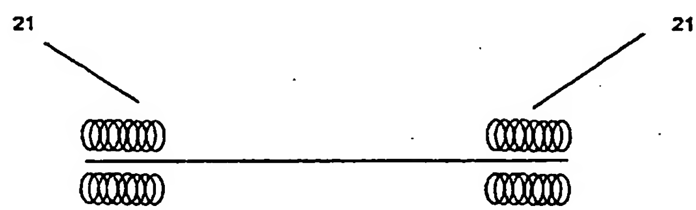

Figure 4

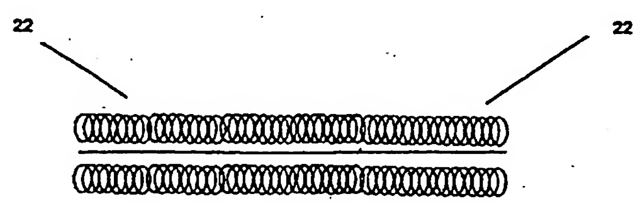

Figure 5

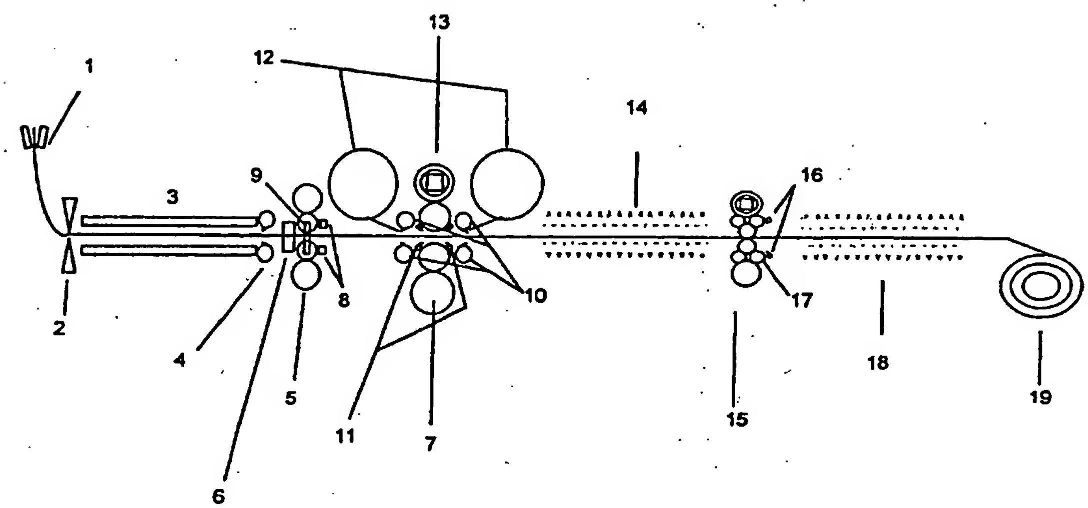

Figure 6

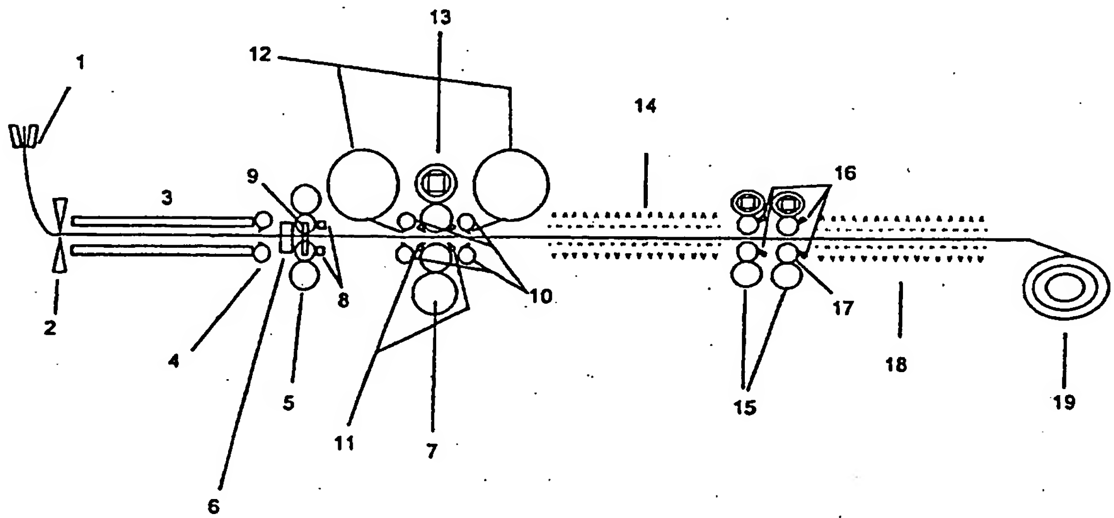

Figure 7

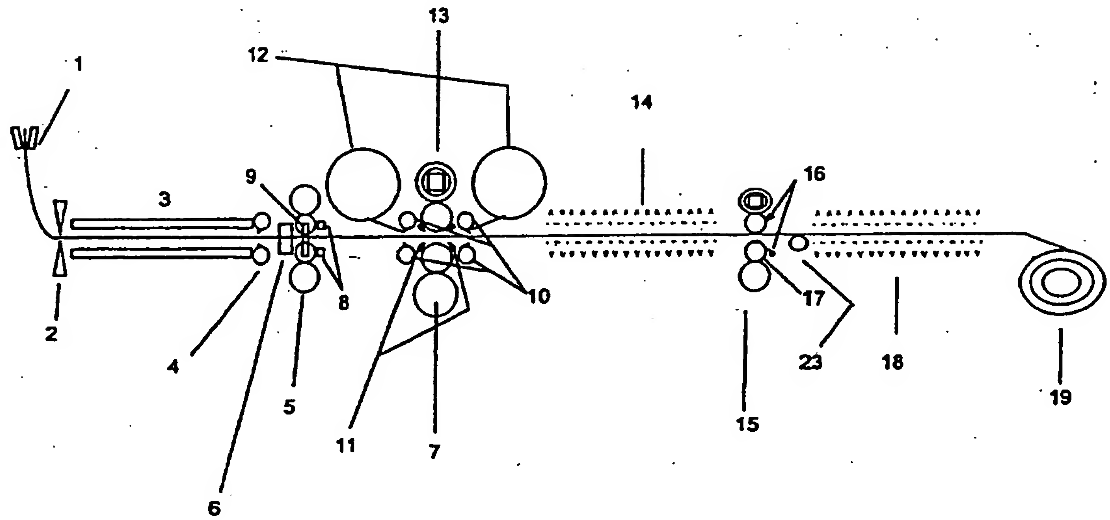

Figure 8

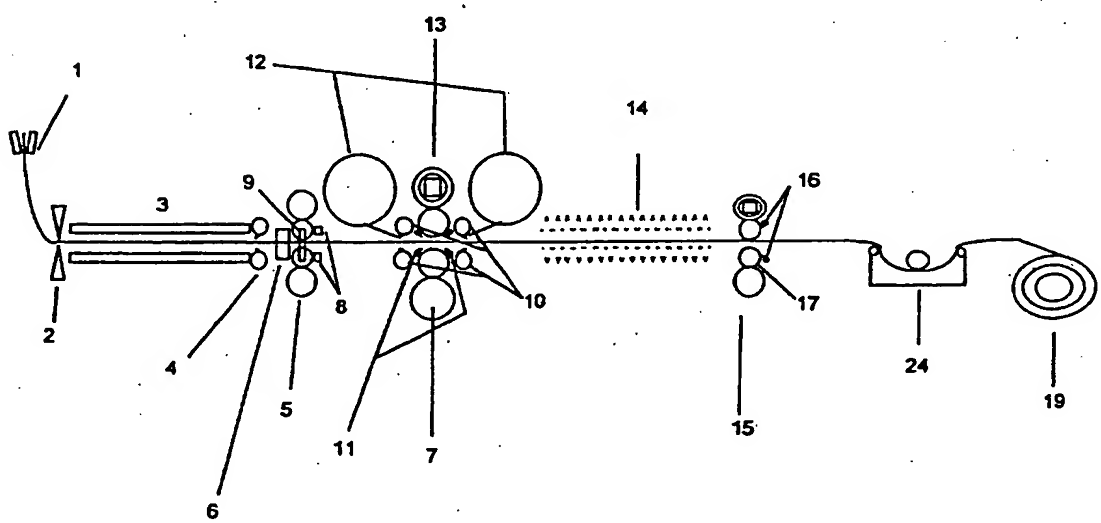

Figure 9

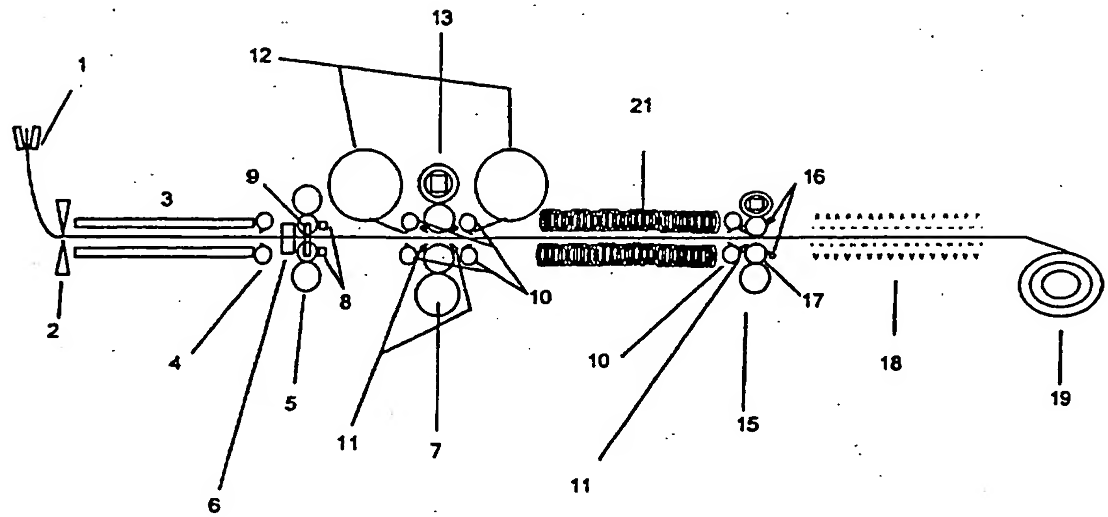

Figure 10

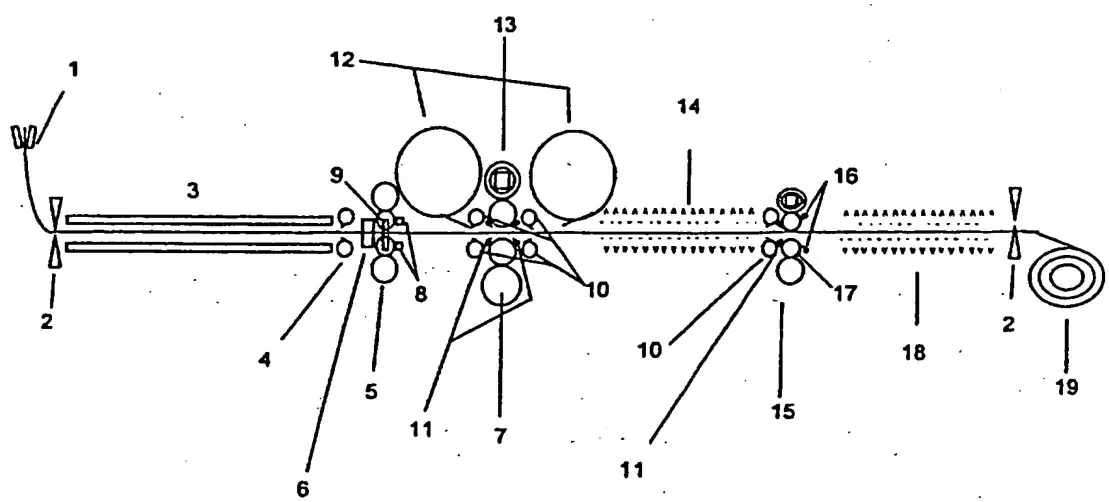

Figure 11

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LOW COST APPARATUS AND METHOD FOR MANUFACTURE OF LIGHT GAUGE STEEL STRIP

The invention relates to a method and apparatus for the manufacture of light gauge steel strip.

Light gauge steel strip is conventionally produced via a process consisting of continuous casting, and both hot rolling and cold rolling. These processes may themselves be followed by various downstream processes (e.g. pickling, annealing, coating). Physical and economic limits currently restrict the production of lighter gauge strip directly off the hot mill, so demanding the need for a cold rolling step.

The invention describes a method and low capital cost apparatus for production of light gauge steel strip by a continuous casting and semi-continuous rolling process. The product produced by this invention can be of such a light gauge that the cold rolling stage may be eliminated altogether and/or the material is in such a metallurgical condition that it is more processable for subsequent cold rolling or other downstream processing.

Ignoring for the moment the details of the roughing mill, hot strip rolling is conventionally performed using either a roughing mill / tandem finishing mill or roughing mill / Steckel mill combination. The design and operation of the latter is revealed in DE2630877A for which the production of a steel rolled in the austenitic condition is the obvious intention. The current

invention however is explicitly designed to enable both austenitic and ferritic / intercritical rolling, with particular emphasis on ferritic rolling of light gauge material.

The throughput of the roughing mill and Steckeling operations must be matched for optimum productivity. For instance US 5689991A and WO 96/40456A both propose intermediate incubation / storage devices to optimise the throughput balance while ensuring a uniform, austenitic finishing temperature. Neither of these Steckel mill upgrades, however, offers a solution to the problem of producing significantly lighter gauge material. The current invention avoids the need for incubation by aiming to roll in the ferritic or intercritical temperature range. By controlling heat removal, strip of uniform temperature is presented to a finishing mill for heavy deformation in the ferritic or intercritical temperature range.

A method for light gauge rolling is presented in EP-A-0 449 004A which places a tandem finishing mill after the Steckel mill so that greater throughput and austenitic finishing temperatures are more easily achieved. It is the clear intention that the number of passes in the Steckel mill is reduced and the reduction sequence passes to the finishing mill at an early stage to increase overall throughput. The invention described herein does not aim to transfer the reduction sequence to the finishing mill but to Steckel the material down to a light gauge prior to applying a single pass further reduction in the finishing mill. In the preferred embodiment of the invention, water cooling is applied between Steckel mill and finishing mill to present strip of a uniform thermal profile, in the ferritic or intercritical temperature range, for subsequent heavy reduction in a single pass.

However, the layout is designed to permit "conventional" austenitic rolling to still be used, taking advantage of the additional extra stand(s) to optimise the reduction sequence.

According to the present invention, there is provided method for the manufacture of light gauge steel strip comprising the following process steps sequentially:

i) steel is continually cast,

ii) the hot cast steel is cut or sheared into slabs and charged into a furnace which either re-heats the material and/or homogenises the temperature and metallurgical quality of the material,

iii) the steel is then descaled,

iv) the steel is then reduced in a reversing stand or stands such as a rougher followed by a Steckel mill, or simply using a Steckel mill,

wherein, when the hot steel strip exits the Steckel mill with a gauge of approximately 1 and is passed in tandem into a finishing mill, characterised in that zoned cooling units are arranged between the Steckel mill exit and the finishing mill to homogenise the temperature along the length and width of the strip and the cooling units may be adjusted to enable a wide range of entry temperatures of the strip to the finishing stand such that the steel strip entering the finishing stand may be in either the intercritical or ferritic phase.

The invention further provides a method wherein the finishing stand incorporates lubricating means and a roll configuration that enables high reductions, typically of the order of 40%, to be taken in either the austenitic

or the intercritical or ferritic phase, according to the product and gauge being produced.

The invention further provides a method wherein the controlled cooling on exit from the finishing stand to permit a range of cooling rates comprises very rapid quenching to achieve rapid cooling and air cooling to achieve slow cooling.

The invention further provides a method wherein the coiling of the strip takes place on a downcoiler close coupled to the finishing stand so that it may be coiled at high temperature, there may be two or more finishing stands.

The invention further provides a method wherein steel is cast continuously to produce a slab of between 30 and 120mm, and wherein the steel is given a high reduction pass of preferably up to 50% in a roughing stand which uses edging to prevent edge cracking and passed preferably in tandem to a Steckel mill.

The invention further provides a method wherein on-stand de-scaling is located at both sides of the Steckel mill and used to remove scale from the stock.

Scale suppression sprays are also preferably provided to control the re-growth of scale between the strip being de-scaled and entering the roll bite.

The invention further provides a method wherein for production of light gauges, the first pass in the Steckel mill preferably takes a further 55% reduction before the steel is fed into a Steckel furnace (12) to minimise heat loss. Three further 55% reductions are preferably taken using the Steckel mill, before a lower reduction of about 20-30% is taken to achieve a preferred exit gauge of about 1.0mm. Preferably, a shape control actuator controls both gauge and shape during rolling.

The invention further provides a method wherein an intermediate temperature control stage is provided between the Steckel mill and the finishing mill both to homogenise the temperature along the length and across the width of the stock and to control the entry temperature to the finishing mill.

The invention further provides a method using a tandem roughing and first Steckeling pass.

The invention further provides a method using 'midi' slab casting or thin slab casting to produce a thin gauge cast bar.

The invention further provides a method wherein temperature homogenising means is provided directly in advance of the Steckel mill, such as an homogenising furnace. Preferably soft reduction equipment is provided between caster and homogenising furnace to reduce slab thickness and increase microstructural integrity before rolling.

The invention further provides a method with edge heating facilities to preferentially heat the edges of the strip prior to finish rolling.

Preferably, full width rapid heating facilities used between the Steckel mill and finishing mill enabling the material to be re-austenitised prior to entry to the roll bite. Strip immersion means may be provided for rapid cooling of the strip.

The invention further provides a method with shape measuring means to measure the shape of the strip while it is under tension.

The invention further provides a method for the production of a wide range of steel grades including low carbon steel, IF steels, Extra low carbon steels, HSLA steels dual-phase steels and stainless steels.

The invention will now be described in more detail with reference to an exemplary embodiment of a method and low capital cost apparatus for production of light gauge steel strip by a continuous casting and semi-continuous rolling process as shown in the following Figures in which:

Fig. 1 is a layout of the apparatus of the invention according to a first embodiment,

Fig. 2 is a layout of the apparatus of the invention according to a second embodiment

Fig. 3 is a cross section through an embodiment of the temperature control stage 14,

Fig. 4 is a cross section through a further embodiment of the temperature control stage 14,

Fig. 5 is a cross section through a further embodiment of the temperature control stage 14, and

Figs. 6 to 11 are layouts of the apparatus of the invention according to further embodiments of the invention.

This invention described herein, is primarily intended as an upgrade to an existing Steckel mill giving the operator the flexibility to produce a wider product mix, have lighter gauge capability and/or increase overall throughput. In this invention, the primary aim is to present (by means of rolling) a light gauge strip in the ferritic or inter-critical condition to the finishing mill such that a high reduction can be performed to obtain the desired metallurgical characteristics on exit, but material may also be presented in the austenitic condition. The use of a thin slab caster, of roughing and Steckel mills as described enables this to be achieved, but as the production of thin cast slabs of sufficient metallurgical quality improves,

there may come a point where it is possible to effectively leave out the roughing mill altogether and simply couple the Steckel mill and finishing mill.

So-called 'ferritic' rolling has also increased in popularity over recent years but the traditional layout of a Steckel mill does not conveniently lend itself to the production of such material. It is the intention of this invention to offer such flexibility to operators of Steckel mills.

The primary scope of the invention is the use of high efficiency cooling equipment and a lubricated finishing stand to enable a complete range of rolling, cooling and coiling conditions to be obtained to maximise the metallurgical product versatility of the invention. However the invention also describes the clear benefits of fronting this equipment with continuous casting and semi-continuous hot rolling apparatus of similar production rate so that the throughput is well balanced. Fronting the high efficiency cooling and lubricated high reduction finishing stand to a Steckel mill in this way, also enables its use 'in-line' since Steckeling may be described as semi-continuous, escaping the so-called 'mass flow trap'. In continuous rolling mills, mass flow dictates an ever increasing strip speed as it is rolled to lighter gauge, making the use the invention described here impractical.

Included in the scope of the invention is a method and combination of apparatus for the manufacture of thin gauge hot rolled steel strip that combines thin slab casting technology with a heavy roughing pass, a Steckeling operation followed by controlled cooling prior to the novel

finishing pass (which is the primary invention), before coiling. The result is a light gauge product of good dimensional quality with optimised and controllable metallurgical properties. The rate of caster production and Steckel mill output are conveniently and preferably balanced at the 1Mtpa level.

The objectives of the invention are three-fold:

(i) A Steckel mill upgrade that gives it an ultra light gauge capability.

(ii) A Steckel mill upgrade that offers a viable ferritic rolling option while permitting production of light gauge austenitically rolled material.

(iii) A plant layout of low capital cost for the production of ultra light gauge strip where throughput is matched to that of a thin slab caster.

However the invention offers further subsidiary benefits which result from production of a ferritically rolled product:

(i) A product in such a form that either eliminates later processing steps due to its thin gauge, or a product that is of improved processability for later processing steps.

(ii) Produce hot band product off the hot mill with accurate dimensional properties and range of metallurgical properties, possible through the versatility of being able to finish rolling over a wide range of temperatures.

The invention is suitable for the production of a wide range of steel strip products but galvanised steel flanging and exposed automobile parts are examples which demonstrate the breath and versatility of the invention.

Wide strip may also be called sheet, but for convenience the term 'strip' only, will be used. The term strip is used to describe the physical dimensions of the product and does not restrict the inventions use to grades of steel which are typically called 'strip products'. The invention may also, for example be adjusted to enable production of so-called 'pipe' and 'structural' grades which include HSLA steels or other compositions including silicon steels and various types of stainless steel. Detailed process descriptions for the production of a variety of steel grades, and the particular arrangement of equipment required are discussed below and form a major part of the content of this invention.

Figure 1 shows the layout of the caster 1 roughing stage 5, steckel mill 7 and finishing stand 15. In this embodiment, the high reduction finishing stand 15 and associated equipment are positioned at exit from a Steckel mill 7. This embodiment of the invention includes tandem rolling between the last Steckeling pass and single finishing mill pass and threading of the close coupled downcoiler prior to acceleration of the equipment up to full speed. This avoids handling difficulties associated with high speed rolling while maximising throughput and yield. The scope also includes cooling the strip such that it may be rolled in either the intercritical or ferritic phase with preferred rolling practices for the production of a variety of strip products forming an integral part of the invention. The steel passes from the caster 1 through a shear 2 to form slabs which enter the furnace 3. The steel is descaled at a high pressure low volume descaling unit 4 before entering the roughing mill 5. The roughing mill includes an edger 6 to minimise edge catching, on roll regrinding means 8, and roll shifting means 9. The strip then enters the steckel mill which comprises descaling stands 10, scale

suppression sprays 11, a shape roll actuator 13, and coiling drums 12. The strip then passes to the controlled cooling stage 14 before entering the finishing mill 15 which includes a high reduction roll configuration 17. The strip is cooled further at cooling stage 18 before coiling at the coiling stage 19. Figure 2 is a layout of this embodiment in which soft reduction 19 is applied during or immediately after casting.

A further embodiment of the invention utilises the core invention (in terms of apparatus and method) in an overall plant layout for the production of light gauge hot strip. A preferred production practise for operation of this equipment also forms part of the invention.

For production of light gauge hot band an in-going strip thickness to the finishing mill of preferably less than 2mm, and 1.5mm would be typical since the greatest benefits of the invention will be found when the finished hot band is significantly less than 1mm gauge. During processing and particularly during transfer to the finishing stand the edges of the strip are liable to cool preferentially to the bulk of the width which may lead to excessive temperature loss and consequent loss in ductility. To overcome this problem the preferred variation of the intermediate cooling section invention uses zoned cooling 20, Figure 3, across the width of the strip so that the edges can effectively be masked to minimise the cross width temperature differential and in particular reduce the degree of edge cooling. A controlled cooling profile would also be used to minimise the head to tail thermal differential along the length of the strip which can be quite marked following the Steckeling operation. Furthermore another embodiment of the invention includes the facility for heating the edges of the strip, Figure

4, preferably using induction heating 21 although other methods may be used.

One of the key benefits of this invention of increasing commercial importance however, is the ability to use the controlled cooling units to lower the temperature of the entire length of the strip to a uniform temperature in the intercritical or ferritic phase. This enables a wide range of commercially important metallurgical products to be produced. The potential benefits in terms of high premium product are similar to those included in a sister patent, such as production of light gauge cold band substitute, soft feedstock for further processing and IF steel production with improved texture. The latter in particular requires the use of lubrication on the finishing stand as described later. The ability to control entry temperature to the finishing mill also enables partially transformed products to be rolled and so-called dual-phase steels to be produced directly off the hot mill. This method of dual-phase steel production (incorporating the high intensity cooling after the finishing mill as described below) alleviates the need for interrupted cooling and the consequential need for long lengths of run out table cooling.

Not only does the invention offer the opportunity to control the precise temperature of finish rolling through the use of intermediate cooling and/or edge induction heating but also the possibility of re-heating the whole strip width as shown in Figure 10 and 5. This is preferably performed by induction heating 22 prior to entry to the finishing stand. The ability to allow the product to transform either wholly or partially and then to re-austenitise it prior to finishing for instance, enables a wider range of

products to be rolled and/or wider range of material properties to be achieved. To control the degree of re-heating, the temperature of the incoming strip is monitored and used to control the output of the induction heating units to enable either a uniform temperature or desired temperature profile to be achieved along the length of the stock when it arrives at the roll bite.

The arrangement of rolls within the finishing stand or stands of the invention are designed to give maximum reduction in gauge in as few passes as possible, preferably one pass. High reductions are beneficial not only for the production of light gauge material, but there are also metallurgical benefits especially for instance for rolling in the ferritic state. In the preferred variation of the invention a single stand will be used to take a reduction of at least 25% but typically 40% or above in a single pass. A simple 4-high configuration, Figure 1, or so-called 'Z-high' configuration of rolls, Figure 6, are preferred, although any suitable means may be used.

A further embodiment includes the use of a second finishing stand, Figure 7, also rolling in tandem with the final Steckel pass and first finishing stand pass. Again, this could be equipped with de-scaling apparatus, and the other equipment mentioned below for the single finishing stand variation, such as lubrication. This enables the production of even thinner light gauge hot band material with the opportunity for two consecutive reductions. One use of this would be for rolling IF steels in the ferritic phase down to very light gauges with an improved metallurgical structure for subsequent processing since generating good texture in the hot mill has an additive effect to overall texture development during subsequent processing.

The finishing stand or stands incorporate(s) (a) lubrication header(s). Hot mill lubrication offers many benefits including increased roll life, better product surface finish and lower rolling loads. In addition, hot mill lubrication offers metallurgical benefits such as a reduction in surface shear and hence improved texture development for the production of a high drawability ferritically rolled IF steel product (described below). There are process and cost benefits of incorporating lubrication technology on the finishing stand or stands rather the Steckel mill.

The use of lubrication enables high reductions to be taken, although this feature is also important for metallurgical reasons as mentioned. The application of lubricating oil to the work rolls of the stand may be performed by any suitable method which will give uniform coverage the roll, but might typically be by jetting an oil/water mixture. To avoid difficulties with threading the high reduction mill, the lubrication system is not initiated until the first lap of the coil has been threaded. The lubrication equipment is then turned on as the mill is accelerated up to full operating speed. This minimises the amount of strip that is rolled without tension/lubrication and ultimately minimises yield loss from the process. A small amount of back tension between the Steckel mill and finishing stand(s), and of front tension between the finishing(s) stand and downcoiler may be used to obtain high reductions

To maximise the range of strip widths over which good shape can be maintained, preferred embodiments of the invention incorporate the use of a shape control actuator on the finishing stand or stands, which may be used

to control shape. One variation would incorporate a DSR® which uses hydraulic cylinders mounted on a beam to flex a rotating sleeve and subsequently control the shape of the product by transferring load to the work roll. This invention is thus capable of producing very wide strip with good shape.

A further variation of the invention uses a shape measuring device, preferably a contact roll (23), Figure 8, to feedback a control signal to the shape control actuator. The preferred method is to use a measuring device which is capable of measuring shape under tension, although any means of shape measurement may be used. The shape measuring roll may be moved into position once the downcoiler has been threaded to avoid damaging it. Control of gauge and shape in the finishing stand or stands is by a feed forward signal from the final Steckeling pass.

The invention may be used to develop a range of metallurgical structures and to maximise the range of products and mechanical properties that may be produced, a rapid cooling device is located between the finishing stand(s) and the down coiler which is used for certain products. The use of these high efficiency cooling units requires only a short length of run out table. Furthermore, when the cooling units are not in use, only a short length of run out table has to be traversed before the material reaches the coiler so enabling high temperature coiling to be carried out if desired, which might be used to allow self annealing, but also minimising yield loss resulting from the non-uniform processing experienced from head to tail along the strip length.

The invention is designed to enable a wide range of cooling rates to be obtained from simple air cooling when 'off', and any cooling rate in between up to a maximum when operated at maximum output. The preferred method of cooling is by the use of water jets or use of an air/water mist but other methods may be used. For instance, one variation of the invention uses immersion of the strip enabling very rapid cooling which is preferable on certain grades. The precise method is optional but might involve using an adjustable roll to immerse the strip (24), Figure 9, to different depths in a water bath which would enable variation of the time the strip spends immersed and hence the degree of cooling. The water temperature may be adjusted to enable a wide range of cooling rates to be obtained and water near its boiling point may be used to remove large amounts of heat very rapidly. A further variant of the invention uses forced air cooling as an alternative cooling method for some products where fans may be fitted in place of or in addition to other cooling equipment.

The primary aim of the invention is production of hot strip down to light gauges but the equipment may also be used to produce thicker gauge material but which is softer and hence more processable for further rolling. For production of this soft hot band material the gauge entering the finishing stand would typically be less than 10mm and preferably less than 7mm. In this situation the material would be transformed to ferrite on transfer between Steckel mill and finishing stand and ferritically rolled at high reduction followed by immediate coiling at as high a temperature to ensure self-annealing of the coil on cooling. The invention includes descriptions of how to use the apparatus to produce a range of products for which more detailed processing descriptions are given below.

One method of improving the metallurgical structure and which leads to high formability steel strip is to control the degree of carbon precipitation, which determines the aging behaviour of the product. The invention facilitates this by offering a wide range of processing conditions, in particular, control of the rate of cooling prior to (as described above) and following rolling.

A further contribution to the development of a desirable metallurgical structure is the ability to control the process of recrystallisation which in turn controls the drawability of the product. It is possible to use the invention to produce unrecrystallised strip that subsequently recrystallises in a downstream process such as hot dip galvanising.

Drawability is measured by the so-called r-value or Lankford value which is controlled by the crystallographic texture of the product. A number of aspects of the invention address the need to be able to control and develop a desirable r-value in the product for good drawability, but three of these are discussed in particular.

The first is that high rolling reductions (large deformations) are taken in the finishing stand or stands, which generate a high dislocation density in the product and hence a large driving force for recrystallisation. In conjunction with control of the rolling temperature this permits a wide range of processing conditions with lower temperature, high reduction rolling being favourable for development of high r-value for IF steels.

The second aspect is that lubrication may be used during the finish rolling process. Without the use of lubrication an undesirable crystallographic texture may be developed in the surfaces of the material in contact with the roll. Lubrication of the rolling process is highly desirable for production of high r-value product particularly for IF steels, when rolled in the ferritic state.

The third aspect of developing high r-value material is the ability to control the rate of cooling of the product after finish rolling between simple air cooling and rapidly water cooling. A slow air cool may be used to enable the product to 'self anneal' on cooling so producing a softer end product. Rapid cooling offers a wide range of possibilities such as the ability to 'freeze in' the as rolled structure, or develop controlled amounts of second phase, in the product.

Due to high reduction taken and the wide range of processing speeds available, the exit speed of the strip from the finishing stand or stands may reach very high speeds when producing light gauges. High speed thin strip is conventionally difficult to thread and coil for these reasons. The invention offers two solutions to this. Firstly since the ROTC cooling section is relatively short, only a minimum yield loss is incurred if the mill is not accelerated until the coiler is threaded. Alternatively, rather than have to thread the downcoiler before accelerating the mill, a shear and downcoiler combination enables threading of strip at up to 20m/s. With this combination of shear and downcoiler and associated strip guiding equipment, full speed guiding of a newly sheared strip end on to the

mandrel can be achieved owing to the proximity of the mandrel to the shearing plane and to the special guiding equipment incorporated therein.

Referring to Figure 1, an embodiment of the method and apparatus of the invention is shown for the production of light gauge ferritically rolled low carbon steel hot band. The material is rolled in the austenitic state in the Steckel mill and the transformation takes place during transfer to the finishing mill through the use of the intermediate cooling section. The strip is then deformed at approximately 750°C and coiled at between 675-700°C to enable it to self-anneal without water cooling used to remove heat from the stock. The product is likely to be formable but not deep-drawable. Uses for this type of steel are as a substitute for cold rolled product, after an optional skin pass for improvement of surface finish to give the material a cold rolled appearance. Another use of the material is as a substrate for hot dip galvanising. Inductive heating of the edges of the strip may be used to maximise product yield.

Referring again to Figure 1, an embodiment is shown for the production of dual-phase steels. In this embodiment, the steel is cooled sufficiently on the intermediate cooling section to be in the partially transformed (ferritic) condition on entry to the finishing mill. The strip is then rolled at relatively high temperature (700-750°C) before high intensity cooling is used to 'quench-in' a second phase, be it martensitic or bainitic. For the production of martensitic dual phase steels, the embodiment for immersing the strip shown in Figure 9 may be used.

A further embodiment of the method and apparatus of the invention is for the production of drawable IF steel hot rolled product. The material must be finished in the austenitic condition in the Steckel mill in order to achieve good drawability. In order to develop good drawability, the lower the temperature of finish rolling (provided it is lubricated) the better so the material may be rapidly cooled down on the intermediate cooling section to anywhere between 400-750°C depending on the properties desired of the final product. Various cooling rates following finishing may be used depending again on the final properties desired.

Referring now to Figure 10, an apparatus arrangement and method is shown for the production of steels where modification of the metallurgical structure and refinement of the grain size is desired, which may be achieved by re-austenitisation. Rapid re-heating is used prior to the finishing mill. The strip is then rolled and the subsequent cooling controlled to generate the desired properties. Steel produced by this method would combine high strength and toughness and it could be used for the production of high strength HSLA steels for structural or pipe stock, direct application of hot mill product.

As discussed previously the invention may conveniently be fronted by a plant layout that is well matched in terms of throughput to that of the Steckel mill / finishing mill combination. For the production of ultra light gauge strip. The following section describe the preferred embodiment of such plant and layout.

Molten steel is cast via any suitable means, into a slab of between 30 and 120mm thickness. For the production of thinner gauge material, the closer to the bottom limit, the better. In one variation of the invention for instance (Figure 2), soft reduction (19) may be used to reduce the stock from an initial size at mould exit to lighter gauge final size prior to homogenising. A typical casting speed of 5m/min is well matched to the output of the Steckel mill when rolling to ultra light gauges (<1.5mm).

Following casting, the stock is cut or sheared, depending on thickness, into slabs and fed through an homogenising furnace which ensures uniformity of temperature and metallurgical quality along the strip length. Various homogenising temperatures are used depending on the material grade and the preferred processing schedule. For instance, for grades that are suitable for, and it is desired to, roll ferritically in the finishing stand, it may be preferred to homogenise the slabs at significantly lower temperatures than for material which is to be finished in the austenitic state.

On exit from the furnace the material is preferably de-scaled using high pressure, low volume de-scaling technology which combines high system pressure with low flow rate de-scaling nozzles. This combination ensures optimum de-scaling performance in terms of the combination of impact pressure and specific impingement rate of water on the strip surface, while causing minimum bulk temperature drop from the stock. Maintaining thin gauge product at desired rolling temperatures throughout processing is a challenge this invention aims to address.

Rather than the material being rolled directly in a Steckel Mill or tandem Steckel mill arrangement, the material is first rolled in a roughing stand which optionally has on-stand de-scaling and also optional scale suppression equipment. A high reduction preferably upto 60% is achieved in the roughing stand and the use of an edger minimises edge cracking during the process. On exit from this pass the strip is fed, in tandem, into the Steckel mill and preferably a further 55% reduction taken before feeding into the exit Steckel drum. The concept of using a roughing stand in advance of the Steckel mill offers a number of distinct advantages in terms of both the process and surface and metallurgical quality:

In terms of the process:

(1) use of the roughing stand reduces the number of Steckeling passes since the roughing stand takes a substantial rolling reduction.

(2) Since the material is passed directly into the first Steckeling pass in tandem, the temperature profile the strip has developed as it enters the Steckel drum is uniform along the length of the stock. The Steckeling operation conventionally generates an adverse temperature profile along the length of the stock, leading particularly to cold head and tail. Since the rougher has effectively reduced the number of Steckeling passes required the degree to which this adverse temperature profile builds up is significantly reduced and as is discussed later, can be almost completely eliminated prior to the final finishing pass.

(3) In contrast to the tandem Steckel mill arrangement the need to enable both stands to operate at both high and low speeds is avoided, reducing significantly the capital cost of equipment.

In terms of metallurgical and surface quality

(1) since the stand incorporates an edger on its entry side, the 'dog-boned' strip resulting from the edging pass is confined to the roughing stand and a 'sized' bar is presented to the Steckel mill. In particular this means that the wear pattern which results from the dog-boning is a problem only on the roughing mill and is not transferred to the Steckel mill, which carries out the finishing operation. This minimises such wear to the Steckel mill work rolls so increasing roll life and giving improved surface quality to the product. This wear pattern in tandem Steckel mill or single Steckel Mill configurations is transferred to the Steckel mill(s) rolls and subsequently to the strip.

(2) General 'roughing' wear, resulting from the highest stock temperatures is also confined to the roughing stand.

(3) the use of work roll shifting on the roughing stand could be used to enable the position of the wear pattern to be shifted so preserving the effective surface quality of the roll for longer. On-line roll grinding on the roughing stand could also be used to minimise the effects of wear and reduce the frequency of roll changes, but both of these options add significantly to the capital cost.

Up to a preferred maximum of four further Steckeling passes, enable a final gauge, on exit from the Steckel Mill, of down to 1.0mm to be achieved without restricting throughput, (provided less than about 20% of the product range is rolled to this gauge). Possible exit gauges from each rolling pass are shown in the table below:

Exit from (Stand/Pass)	Product Dimension (mm)

Rougher	28
1st Steckel mill pass	14
2nd Steckel mill pass	7
3rd Steckel mill pass	3.5
4th Steckel mill pass	1.6
5th Steckel mill pass	1.1
Finishing Pass	0.5-0.7

To maximise surface quality during the Steckeling operation, the build up of scale is minimised by a combination of HP/LF de-scaling and scale suppression technologies on-both entry and exit to the stand. HP/LF de-scaling will ensure optimum removal of scale from the stock surface. The benefits of carefully controlled scale suppression sprays are two-fold. Primarily, these minimise re-growth of scale between the de-scaling unit and the roll bite but, at least as significant is the beneficial effect on roll life. The sprays may be positioned and adjusted so that the surface temperature of the strip that comes into contact with the roll at entry is as low as possible without excessive removal of heat from the bulk of the stock. This reduces the rate of roll wear, so prolonging roll life and preserving the roll surface quality for a longer period.

As with any Steckeling operation a temperature differential will develop along the length of the stock leading in particular to cold head and tail. For instance for a typical exit temperature of about 1000°C along the bulk of the length of the stock the head and tail may be as low as 920°C. This invention attempts to keep the number of Steckeling passes as low as possible so minimising this effect in line with the aims of the invention.

Use of the high efficiency cooling units between the Steckel mill and finishing stand enable the strip temperature to the finishing mill to be accurately controlled. The primary use of these cooling units is to control the water flow so minimising the head to tail temperature profile developed during Steckeling. Using variable flow, it should be possible to obtain a near uniform temperature along the entire strip length prior to finishing mill entry. For maximum yield benefit, minimising the head and tail temperature profile and generating as uniform a temperature profile along the strip length as possible during the finishing pass is desirable.

In one variation of this invention, Figure 11, the slabs are sheared to approximately 60 tonne lengths rather than the more typical 30 tonne weights, with the homogenising furnace and Steckel drums modified to suit. The material is then processed as described above through the roughing, Steckeling and finishing operations, before being sheared at high speed immediately prior to the down coiler into two conventional coil weights of approximately 30 tonne.

This method has a number of distinct advantages that outweigh the increased capital cost of the apparatus. One is the increased yield since there are effectively only two ends of the stock that have to be cropped rather than four 'ends' that would have to be cropped from the an equivalent length of strip produced in 30 tonne batches. Another benefit is that the ends of the stock are resident on the Steckel drum mandrel for increased times so the effectiveness of the drums is increased and a more uniform temperature profile develops along the length.

CLAIMS

1. A method for the manufacture of light gauge steel strip comprising the following process steps sequentially:

i) steel is continually cast (1),

ii) the hot cast steel is cut or sheared into slabs and charged into a furnace (3) which either reheats and/or homogenises the temperature and metallurgical quality of the material,

iii) the steel is then descaled,

iv) the steel is then reduced in a roughing stand (5) and then rolled in a Steckel mill (7), or is reduced directly in a Steckel mill,

wherein, when the hot steel strip exits the Steckel mill with a gauge of approximately 1 and is passed in tandem into a finishing mill, characterised in that zoned cooling units are arranged between the Steckel mill exit and the finishing mill to homogenise the temperature along the length and width of the strip and the cooling units may be adjusted to enable a wide range of entry temperatures of the strip to the finishing stand such that the steel strip entering the finishing stand may be in either the intercritical or ferritic phase.

2. A method according to claim 1, characterised in that the finishing stand (15) incorporates lubricating means (16) and a roll configuration (17) that enables high reductions, typically of the order of 40%, to be taken in either the austenitic or the intercritical or ferritic phase, according to the product and gauge being produced.

3. A method according to claim 1, characterised in that the controlled cooling (18) on exit from the finishing stand to permit a range of

cooling rates comprises very rapid quenching to achieve rapid cooling and air cooling to achieve slow cooling.

4. A method according to claim 1, characterised in that the coiling of the strip takes place on a downcoiler close coupled to the finishing stand so that it may be coiled at high temperature.

5. A method according to claim 1, with two or more finishing stands.

6. A method according to claim 1, characterised in that steel is cast (1) continuously to produce a slab of between 30 and 120mm.

7. A method according to claim 1, characterised in that the steel is given a high reduction pass of preferably up to 50% in a roughing stand (5) which uses edging (6) to prevent edge cracking and passed preferably in tandem to a Steckel mill (7).

8. A method according to claim 1, characterised in that the on-stand de-scaling (10) located at both sides of the Steckel mill and used to remove scale from the stock.

9. A method according to claim 1, characterised in that the scale suppression sprays (11) are provided to control the re-growth of scale between the strip being de-scaled and entering the roll bite.

10. A method according to claim 1, characterised in that for production of light gauges, the first pass in the Steckel mill preferably takes a further 55% reduction before the steel is fed into a Steckel furnace (12) to minimise heat loss.

11. A method according to claim 1, characterised in that the three further 55% reductions are preferably taken using the Steckel mill, before a

lower reduction of about 20-30% is taken to achieve a preferred exit gauge of about 1.0mm.

12. A method according to claim 1, characterised in that a shape control actuator (13) controls both gauge and shape during rolling.

13. A method according to any preceding claim, characterised in that an intermediate temperature control stage is provided between the Steckel mill and the finishing mill both to homogenise the temperature along the length and across the width of the stock and to control the entry temperature to the finishing mill.

14. A method according to any preceding claim, using a tandem roughing and first Steckeling pass.

15. A method according to any preceding claim, using 'midi' slab casting or thin slab casting to produce a thin gauge cast bar.

16. A method according to any preceding claim, characterised in that temperature homogenising means is provided directly in advance of the Steckel mill, such as an homogenising furnace.

17. A method according to any preceding claim, using a shape control actuator to control both gauge and shape during rolling on either or both the Steckel mill and finishing mill.

18. A method according to any preceding claim, with soft reduction equipment between caster and homogenising furnace to reduce slab thickness and increase microstructural integrity before rolling.

19. A method according to any preceding claim, with edge heating facilities to preferentially heat the edges of the strip prior to finish rolling.

20. A method according to any preceding claim, with full width rapid heating facilities used between the Steckel mill and finishing mill enabling the material to be re-austenitised prior to entry to the roll bite.

21. A method according to any preceding claim, with shape measuring means to measure the shape of the strip while it is under tension.

22. A method according to any one of claims 1 to 16, including a strip immersion means for rapid cooling of the strip.

23. A method according to any one of claims 1 to 17, for the production of a wide range of steel grades including low carbon steel, IF steels, Extra low carbon steels, HSLA steels dual-phase steels and stainless steels.

Amendments to the claims have been filed as follows

1. A method for the manufacture of light gauge steel strip comprising the following process steps sequentially:

i) steel is continually cast (1),

ii) the hot cast steel is cut or sheared into slabs and charged into a furnace (3) which either reheats and/or homogenises the temperature and metallurgical quality of the material,

iii) the steel is then descaled,

iv) the steel is then reduced in a roughing stand (5) and then rolled in a Steckel mill (7), or is reduced directly in a Steckel mill,

wherein, when the hot steel strip exits the Steckel mill with a gauge of approximately 1 mm and is passed in tandem into a finishing mill, characterised in that zoned cooling units are arranged between the Steckel mill exit and the finishing mill to homogenise the temperature along the length and width of the strip and the cooling units may be adjusted to enable a wide range of entry temperatures of the strip to the finishing stand such that the steel strip entering the finishing stand may be in either the austenitic phase, the ferritic phase, or in the intercritical temperature range where the material is a mixture of austenitite and ferrite.

2. A method according to claim 1, characterised in that the finishing stand (15) incorporates lubricating means (16) and a roll configuration (17) that enables high reductions, typically of the order of 40%, to be taken in either the austenitic phase, the ferritic phase, or.in the intercritical temperature range where the material is a mixture of austenitite and ferrite, according to the product and gauge being produced.

3. A method according to either previous claim, characterised in that controlled cooling (18) is provided on exit from the finishing stand to permit a range of cooling rates including very rapid quenching to achieve rapid cooling and air cooling to achieve slow cooling.

4. A method according to any previous claim, characterised in that the strip is coiled on a downcoiler close coupled to the finishing stand so that it may be coiled at high temperature.

5. A method according to any previous claim, with two or more finishing stands.

6. A method according to any previous claim, characterised in that steel is cast (1) continuously to produce a slab of between 30 and 120mm.

7. A method according to claim 1, characterised in that the steel is given a high reduction pass of preferably up to 50% in a roughing stand (5) which uses edging (6) to prevent edge cracking and passed preferably in tandem to a Steckel mill (7).

8. A method according to any previous claim, characterised in that the on-stand de-scaling (10) located at both sides of the Steckel mill and used to remove scale from the stock.

9. A method according to any previous claim, characterised in that the scale suppression sprays (11) are provided to control the re-growth of scale between the strip being de-scaled and entering the roll bite.

10. A method according to any previous claim, characterised in that for production of light gauges, the first pass in the Steckel mill takes a further 55% reduction before the steel is fed into a Steckel furnace (12) to minimise heat loss.

11. A method according to any previous claim, characterised in that the three further 55% reductions are preferably taken using the Steckel mill,

before a lower reduction of about 20-30% is taken to achieve the required exit gauge.

12. A method according to any previous claim, characterised in that a shape control actuator (13) controls both gauge and shape during rolling.

13. A method according to any previous claim, characterised in that an intermediate temperature control stage is provided between the Steckel mill and the finishing mill both to homogenise the temperature along the length and across the width of the stock and to control the entry temperature to the finishing mill.

14. A method according to any previous claim, using a tandem roughing and first Steckeling pass.

15. A method according to any previous claim, using 'midi' slab casting or thin slab casting to produce a thin gauge cast bar.

16. A method according to any previous claim, characterised in that temperature homogenising means is provided directly in advance of the Steckel mill, such as an homogenising furnace.

17. A method according to any previous claim, using a shape control actuator to control both gauge and shape during rolling on either or both the Steckel mill and finishing mill.

18. A method according to any previous claim, with soft reduction equipment between caster and homogenising furnace to reduce slab thickness and increase microstructural integrity before rolling.

19. A method according to any previous claim, with edge heating facilities to preferentially heat the edges of the strip prior to finish rolling.

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Application No: GB 9903168.4 **Examiner:** A.R.Martin
Claims searched: **Date of search:** 17 March 1999

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.Q): B3A,B3M

Int Cl (Ed.6): B21B 1/00

Other: On line databases WPI,EDOC,JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
A	WO 96/41024 A	Ipsco see page 18 line 20-page 19 line 5	Claim 1 at least
A	US 5810951 A	Ipsco see column 6 lines 40-60	"

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
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